

LIDAR REMOTE SENSING DATA COLLECTION: Oregon Parks and Recreation Department

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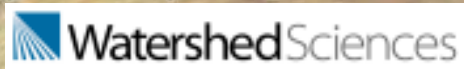
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OREGON PARKS AND RECREATION DEPT.

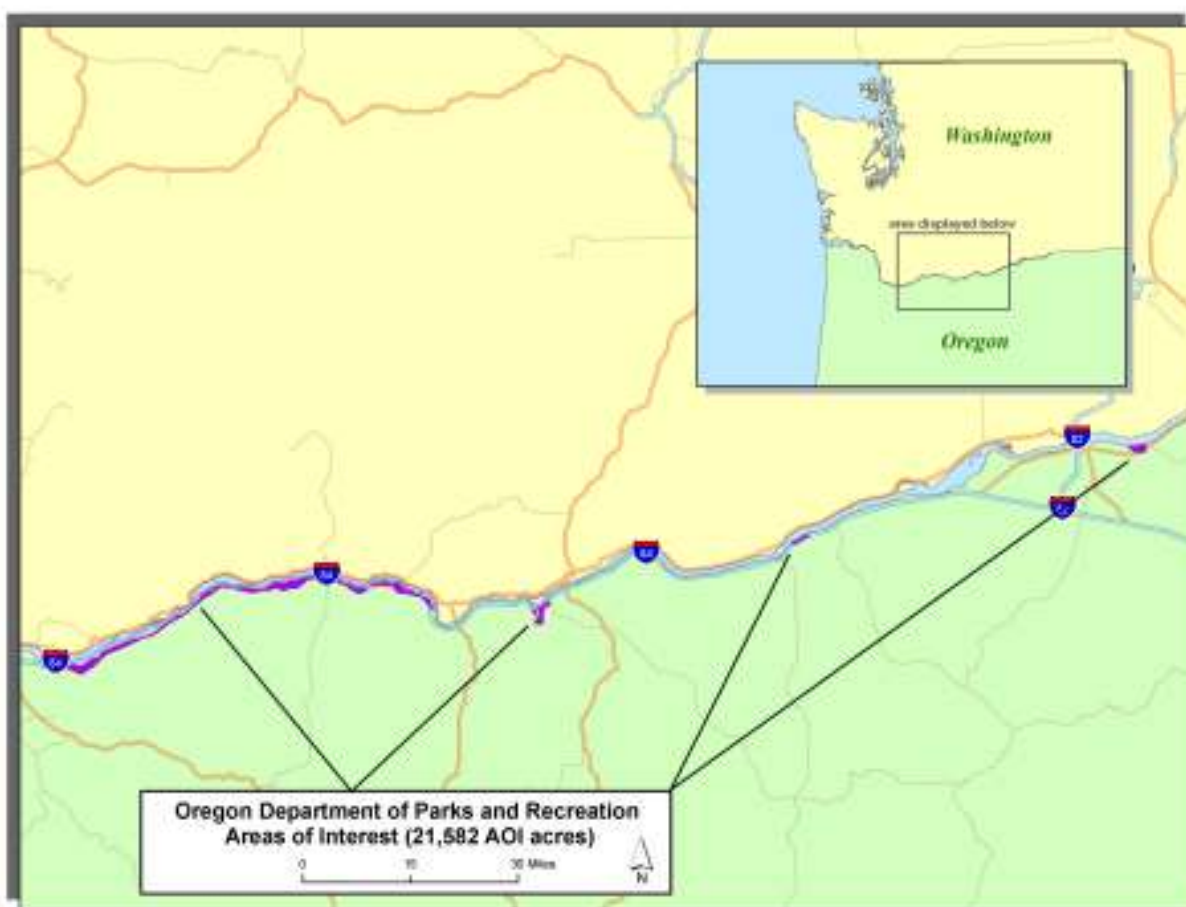
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1. Overview

Watershed Sciences, Inc. (WS) is collecting Light Detection and Ranging (LiDAR) data for the Oregon Department of Parks and Recreation (OPRD) along the Columbia River corridor in Oregon. This acquisition is part of a larger LiDAR survey effort for the U.S. Army Corps of Engineers (ACOE). OPRD data were processed coincident with the ACOE data. For this reason, several statistical reports and processing descriptions apply to the larger LiDAR survey. The requested AOI (**Figure 1**) area for this delivery is 21,582 acres. The area was expanded to include a 100 meter buffer to ensure complete coverage and adequate point densities around survey area boundaries, resulting in 27,577 acres of delivered data. LiDAR data for the OPRD survey was collected between December 7, 2009 and February 22, 2010. This area includes portions of the Columbia River Gorge, as well as three smaller areas east of Hood River, OR.

Figure 1. Oregon Parks and Recreation Dept. (OPRD) survey area.



2. Acquisition

2.1 Airborne Survey - Instrumentation and Methods

The LiDAR survey uses Leica ALS50 Phase II and ALS60 laser systems. For the OPRD/Columbia River survey sites, the sensor scan angle was $\pm 14^\circ$ from nadir¹ with a pulse rate designed to yield an average native density (number of pulses emitted by the laser system) of ≥ 8 points per square meter over terrestrial surfaces. It is not uncommon for some types of surfaces (e.g. water) to return fewer pulses than the laser originally emitted. These discrepancies between 'native' and 'delivered' density will vary depending on terrain, land cover and the prevalence of water bodies.



The Cessna Caravan is a stable platform, ideal for flying slow and low for high density projects. The Leica ALS60 sensor head installed in the Caravan is shown on the left.

All areas were surveyed with an opposing flight line side-lap of $\geq 60\%$ ($\geq 100\%$ overlap) to reduce laser shadowing and increase surface laser painting. The Leica laser systems allow up to four range

measurements (returns) per pulse, and all discernable laser returns were processed for the output dataset.

To accurately solve for laser point position (geographic coordinates x, y, z), the positional coordinates of the airborne sensor and the attitude of the aircraft were recorded continuously throughout the LiDAR data collection mission. Aircraft position was measured twice per second (2 Hz) by an onboard differential GPS unit. Aircraft attitude was measured 200 times per second (200 Hz) as pitch, roll and yaw (heading) from an onboard inertial measurement unit (IMU). To allow for post-processing correction and calibration, aircraft/sensor position and attitude data are indexed by GPS time.



¹ Nadir refers to the perpendicular vector to the ground directly below the aircraft. Nadir is commonly used to measure the angle from the vector and is referred to a "degrees from nadir".

2.2 Ground Survey - Instrumentation and Methods

The following ground survey data were collected to enable the geo-spatial correction of the aircraft positional coordinate data collected throughout the flight, and to allow for quality assurance checks on final LiDAR data products.



2.2.1 Survey Control

Simultaneous with the airborne data collection mission, we conducted multiple static (1 Hz recording frequency) ground surveys over monuments with known coordinates (Table 2). Survey control monuments were occupied by a Trimble GPS base station for an initial period of at least eight hours. All monuments were occupied during a subsequent second session with an observation period of at least four hours. Additional occupations were conducted as necessary. GPS measurements were made with dual frequency L1-L2 receivers with carrier-phase correction.

As an initial check, the NGS on-line positioning user service (OPUS), was used to generate a corrected position for all base station observations. OPUS provides a measurement solution based on three surrounding continuously operating reference stations (CORS). OPUS output includes a solution report with positional accuracy confidence intervals for adjusted coordinates and elevations. The solution report is one component in assessing the quality of the OPUS GPS measurement solutions. Statistical checks of GPS base station positions and repeat control observations include the OPUS solution extended output report. In addition, the standard deviation, kurtosis, and skew of the measurement distribution for each base station occupation were compared. Longitude, latitude, and elevation distributions were separated, and graphic distributions of the positions were plotted for consistency.

Indexed by time, these GPS data are used to correct the continuous onboard measurements of aircraft position recorded throughout the mission. Control monuments were located within 13 nautical miles of the survey area(s).

David Evans and Associates (DEA) provided the official quality assurance and control checks of all monuments in the OPRD/Columbia River project. DEA provided official coordinates for each monument through the OPUS online datasheet publication tool located on the USGS website. All monuments established by Watershed Sciences were published and made publicly available by DEA on the OPUS online datasheet website.

Table 2. DEA Certified Survey Control coordinates for Columbia Survey, UTM Zones 10 and 11.

Base Station ID	Datum: NAD83 (CORS96)		GRS80
	Latitude	Longitude	Ellipsoid Z (m)
1001-51	45 32 52.95214	122 24 43.61919	-13.122
1001-80	45 42 49.27090	121 30 39.83749	6.517
1001-81	45 40 29.62695	121 15 50.33345	11.637
1001-82	45 38 19.36273	120 58 01.24913	207.447
1001-83	45 43 47.54805	120 39 04.19716	75.569
1001-84	45 42 04.13225	120 20 40.20502	150.893
1001-85	45 47 05.76648	120 02 18.05975	109.677
1001-68	45 42 41.45723	121 46 39.21045	13.71
1001-69	45 36 09.27612	122 02 37.57830	0.203
1001-102	45 33 50.44222	122 13 19.83210	159.735

2.2.2 RTK Survey

To enable assessment of LiDAR data accuracy, ground check points were collected using GPS based real-time kinematic (RTK) surveying. Instrumentation included multiple Trimble DGPS units (R8). RTK surveying allows for precise location measurements with an error (σ) of ≤ 1.5 cm (0.6 in).

For the RTK survey, the ground crew used a roving unit to receive radio-relayed corrected positional coordinates for all ground truth points from a GPS base station set up over certified survey control monuments. **Figure 2**, below, portrays the distribution of RTK point and base station locations used for the current delivery of Columbia River survey areas. RTK points were collected on hard surfaces that were easily distinguishable within the LiDAR dataset. Paved surfaces, including roads, paths, and parking lots, were the primary surface target. After all paved surfaces had been exhausted, hard packed gravel roads became the secondary target for RTK, followed by hard packed dirt roads. Hard surfaces are targeted in areas that are clearly visible (and likely to remain visible) from the sky during data acquisition.

In order to facilitate comparisons with LiDAR data, RTK measurements were not taken on highly reflective surfaces such as center line stripes or lane markings on roads. RTK points were taken no closer than one meter to any nearby terrain breaks such as road edges or drop offs to ensure an accurate comparison between RTK and LiDAR ground data. In addition, attempts were made to collect RTK points on locations that could be readily identified and occupied during subsequent field visits. RTK measurements were collected approximately 1-2 meters from one another to support measurement independence.

An RTK point acquisition period is five seconds long and includes three individual one-second measurements averaged together. The five second observation period ensures that an accurate RTK point was taken. RTK points were not taken during periods when PDOP was greater than three, when less than six satellites were visible, or when horizontal and vertical RMS values were greater than 0.03 m. An RMS value of 0.03 m indicates that an RTK measurement is within 0.03 m of its actual position 68% of the time. An RTK check point was also taken at the beginning and end of each RTK session as close to the base station location as possible to provide an on-the-spot vertical accuracy check.

Figure 2. RTK point and control monument location examples. As noted in the text, the data used are part of the larger Columbia River survey. In most cases, control data falls outside of the OPRD Study Area, but within the larger survey area.



3. LiDAR Data Processing

3.1 Applications and Work Flow Overview

1. Resolved kinematic corrections for aircraft position data using kinematic aircraft GPS and static ground GPS data.

Software: Waypoint GPS v.8.10, Trimble Geomatics Office v.1.62

2. Developed a smoothed best estimate of trajectory (SBET) file that blends post-processed aircraft position with attitude data. Sensor head position and attitude were calculated throughout the survey. The SBET data were used extensively for laser point processing.

Software: IPAS v.1.35

3. Calculated laser point position by associating SBET position to each laser point return time, scan angle, intensity, etc. Created raw laser point cloud data for the entire survey in *.las (ASPRS v. 1.2) format.

Software: ALS Post Processing Software v.2.69

4. Imported raw laser points into manageable blocks (less than 500 MB) to perform manual relative accuracy calibration and filter for pits/birds. Ground points were then classified for individual flight lines (to be used for relative accuracy testing and calibration).

Software: TerraScan v.10.009

5. Using ground classified points per each flight line, the relative accuracy was tested. Automated line-to-line calibrations were then performed for system attitude parameters (pitch, roll, heading), mirror flex (scale) and GPS/IMU drift. Calibrations were performed on ground classified points from paired flight lines. Every flight line was used for relative accuracy calibration.

Software: TerraMatch v.10.006

6. Position and attitude data were imported. Resulting data were classified as ground and non-ground points. Statistical absolute accuracy was assessed via direct comparisons of ground classified points to ground RTK survey data. Data were then converted to orthometric elevations (NAVD88) by applying a Geoid03 correction. Ground models were created as a triangulated surface and exported as ArcInfo ASCII grids at a 1 -meter pixel resolution.

Software: TerraScan v.10.009, ArcMap v. 9.3.1, TerraModeler v.10.004

3.2 Aircraft Kinematic GPS and IMU Data

LiDAR survey datasets were referenced to the 1 Hz static ground GPS data collected over pre-surveyed monuments with known coordinates. While surveying, the aircraft collected 2 Hz kinematic GPS data, and the onboard inertial measurement unit (IMU) collected 200 Hz aircraft attitude data. Waypoint GPS v.8.10 was used to process the kinematic corrections for the aircraft. The static and kinematic GPS data were then post-processed after the survey to obtain an accurate GPS solution and aircraft positions. IPAS v.1.35 was used to develop a trajectory file that includes corrected aircraft position and attitude information. The trajectory data for the entire flight survey session were incorporated into a final smoothed best estimated trajectory (SBET) file that contains accurate and continuous aircraft positions and attitudes.

3.3 Laser Point Processing

Laser point coordinates were computed using the IPAS and ALS Post Processor software suites based on independent data from the LiDAR system (pulse time, scan angle), and aircraft trajectory data (SBET). Laser point returns (first through fourth) were assigned an associated (x, y, z) coordinate along with unique intensity values (0-255). The data were output into large LAS v. 1.2 files; each point maintains the corresponding scan angle, return number (echo), intensity, and x, y, z (easting, northing, and elevation) information.

These initial laser point files were too large for subsequent processing. To facilitate laser point processing, bins (polygons) were created to divide the dataset into manageable sizes (< 500 MB). Flightlines and LiDAR data were then reviewed to ensure complete coverage of the survey area and positional accuracy of the laser points.

Laser point data were imported into processing bins in TerraScan, and manual calibration was performed to assess the system offsets for pitch, roll, heading and scale (mirror flex). Using a geometric relationship developed by Watershed Sciences, each of these offsets was resolved and corrected if necessary.

LiDAR points were then filtered for noise, pits (artificial low points) and birds (true birds as well as erroneously high points) by screening for absolute elevation limits, isolated points and height above ground. Each bin was then manually inspected for remaining pits and birds and spurious points were removed. In a bin containing approximately 7.5-9.0 million points, an average of 50-100 points are typically found to be artificially low or high. Common sources of non-terrestrial returns are clouds, birds, vapor, haze, decks, brush piles, etc.

Internal calibration was refined using TerraMatch. Points from overlapping lines were tested for internal consistency and final adjustments were made for system misalignments (i.e., pitch, roll, heading offsets and scale). Automated sensor attitude and scale corrections yielded 3-5 cm improvements in the relative accuracy. Once system misalignments were corrected, vertical GPS drift was then resolved and removed per flight line, yielding a slight improvement (<1 cm) in relative accuracy.

The TerraScan software suite is designed specifically for classifying near-ground points (Soininen, 2004). The processing sequence began by removing all points that were not near the earth based on geometric constraints used to evaluate multi-return points. The resulting

bare earth (ground) model was visually inspected and additional ground point modeling was performed in site-specific areas to improve ground detail. This manual editing of ground often occurs in areas with known ground modeling deficiencies such as: bedrock outcrops, cliffs, deeply incised stream banks, and dense vegetation. In some cases, automated ground point classification erroneously included known vegetation (i.e., understory, low/dense shrubs, etc.). These points were manually reclassified as non-grounds. Ground surface rasters were developed from triangulated irregular networks (TINs) of ground points.

4. LiDAR Accuracy Assessment

Our LiDAR quality assurance process uses the data from the real-time kinematic (RTK) ground survey conducted in the survey area. 4,293 RTK GPS measurements were collected on hard surfaces distributed among multiple flight swaths. To assess absolute accuracy, we compared the location coordinates of these known RTK ground survey points to those calculated for the closest laser points.

4.1 Laser Noise and Relative Accuracy

Laser point absolute accuracy is largely a function of laser noise and relative accuracy. To minimize these contributions to absolute error, we first performed a number of noise filtering and calibration procedures prior to evaluating absolute accuracy.

Laser Noise

For any given target, laser noise is the breadth of the data cloud per laser return (i.e., last, first, etc.). Lower intensity surfaces (roads, rooftops, still/calm water) experience higher laser noise. The laser noise range for this survey was approximately 0.02 meters.

Relative Accuracy

Relative accuracy refers to the internal consistency of the data set - the ability to place a laser point in the same location over multiple flight lines, GPS conditions, and aircraft attitudes. Affected by system attitude offsets, scale, and GPS/IMU drift, internal consistency is measured as the divergence between points from different flight lines within an overlapping area. Divergence is most apparent when flight lines are opposing. When the LiDAR system is well calibrated, the line-to-line divergence is low (<10 cm). See Appendix A for further information on sources of error and operational measures that can be taken to improve relative accuracy.

Relative Accuracy Calibration Methodology

1. Manual System Calibration: Calibration procedures for each mission require solving geometric relationships that relate measured swath-to-swath deviations to misalignments of system attitude parameters. Corrected scale, pitch, roll and heading offsets were calculated and applied to resolve misalignments. The raw divergence between lines was computed after the manual calibration was completed and reported for each survey area.
2. Automated Attitude Calibration: All data were tested and calibrated using TerraMatch automated sampling routines. Ground points were classified for each individual flight line and used for line-to-line testing. System misalignment offsets (pitch, roll and heading) and scale were solved for each individual mission and applied to respective

mission datasets. The data from each mission were then blended when imported together to form the entire area of interest.

3. Automated Z Calibration: Ground points per line were used to calculate the vertical divergence between lines caused by vertical GPS drift. Automated Z calibration was the final step employed for relative accuracy calibration.

4.2 Absolute Accuracy

The vertical accuracy of the LiDAR data is described as the mean and standard deviation ($\sigma \sim \sigma$) of divergence of LiDAR point coordinates from RTK ground survey point coordinates. To provide a sense of the model predictive power of the dataset, the root mean square error (RMSE) for vertical accuracy is also provided. These statistics assume the error distributions for x, y, and z are normally distributed, thus we also consider the skew and kurtosis of distributions when evaluating error statistics.

Statements of statistical accuracy apply to fixed terrestrial surfaces only and may not be applied to areas of dense vegetation or steep terrain. To calibrate laser accuracy for the OPRD LiDAR dataset, 4,293 RTK points were collected on fixed, hard-packed road surfaces within the USACE survey area.

5. Study Area Results

Summary statistics for point resolution and accuracy (relative and absolute) of the LiDAR data collected in the Columbia River survey areas are presented below in terms of central tendency, variation around the mean, and the spatial distribution of the data (for point resolution by quadrangle).

5.1 Data Summary

Table 3. Resolution and Accuracy - Specifications and Achieved Values

Resolution:	Targeted	Achieved
Pulse density	≥ 8 points/m ²	10.32 points/m ²
Vertical Accuracy (1 σ):	<15 cm	5 cm

5.2 Data Density/Resolution

The average first-return density of the UTM 10 delivered dataset is 10.32 points per square meter (**Table 3**). The initial dataset, acquired to be 8 points per square meter, was filtered as described previously to remove spurious or inaccurate points. Additionally, some types of surfaces (i.e., dense vegetation, breaks in terrain, steep slopes, water) may return fewer pulses (delivered density) than the laser originally emitted (native density).

Ground classifications were derived from automated ground surface modeling and manual, supervised classifications where it was determined that the automated model had failed. Ground return densities will be lower in areas of dense vegetation, water, or buildings.

The maps in **Figures 5 and 6** identify the average native and ground point densities for each USGS 0.75 minute quad. Tiles with greater than 20 million points were divided into quarters to keep LAS file sizes manageable.

LiDAR data resolution for the OPRD study areas

- Average Point (First Return) Density = 0.96 pts/ft² (10.32 points/m²)
- Average Ground Point Density = 0.15 pts/ft² (1.57 points/m²)

Figure 3. Density distribution for first return laser points.

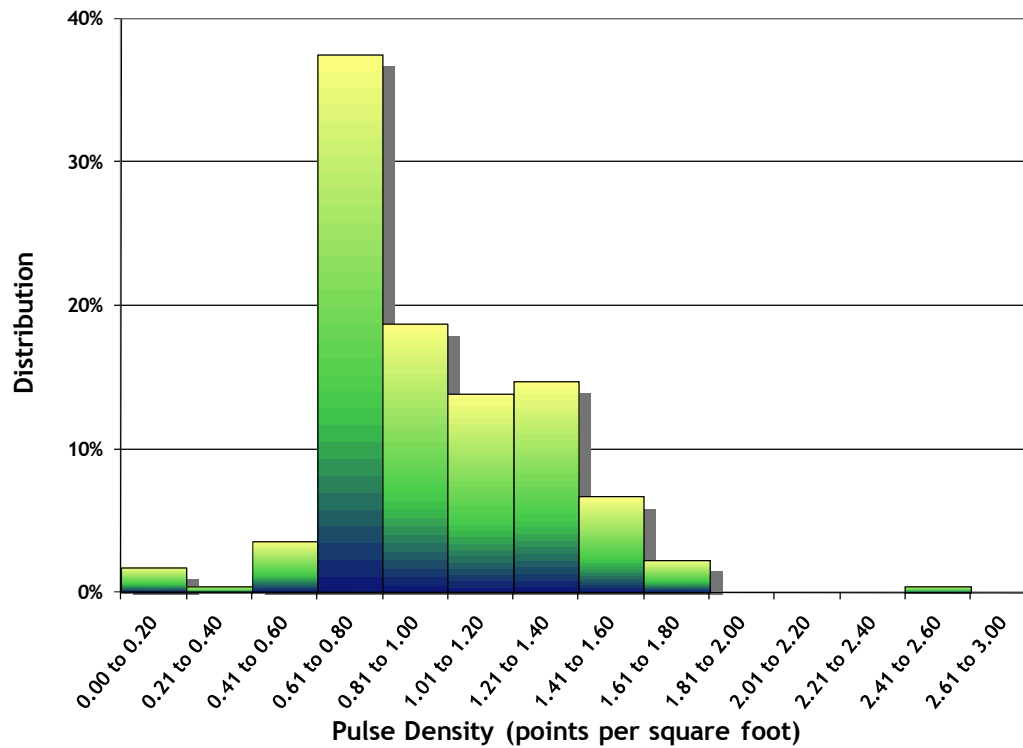


Figure 4. Density distribution for ground classified laser points.

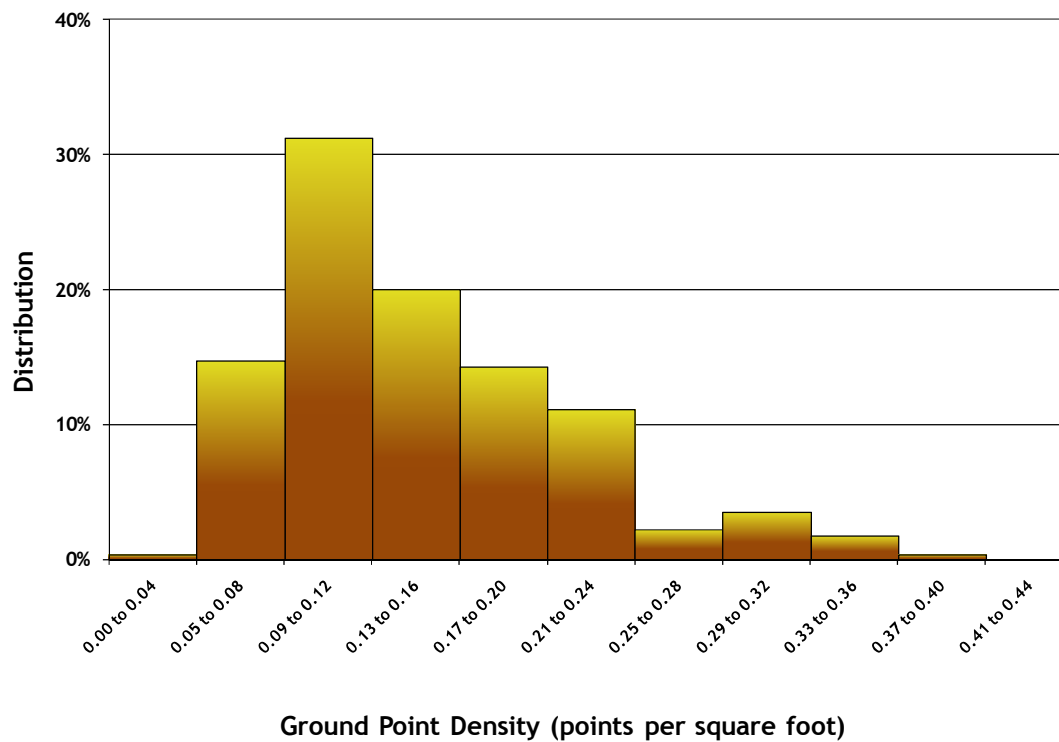


Figure 5. Density distribution map for first return points by USGS 0.75 minute quads.

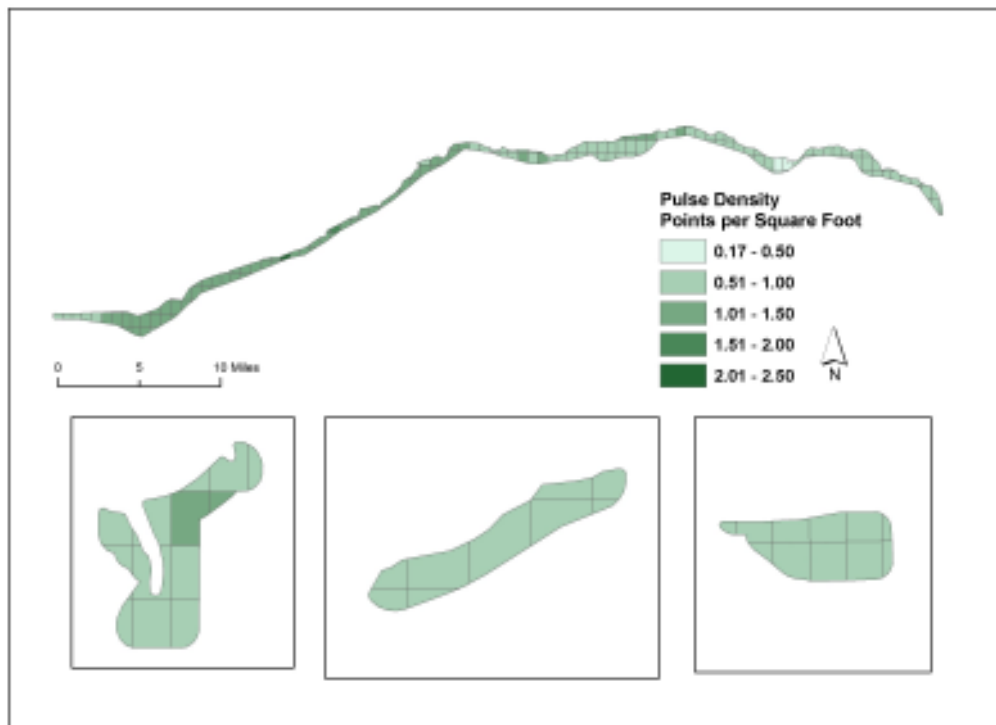
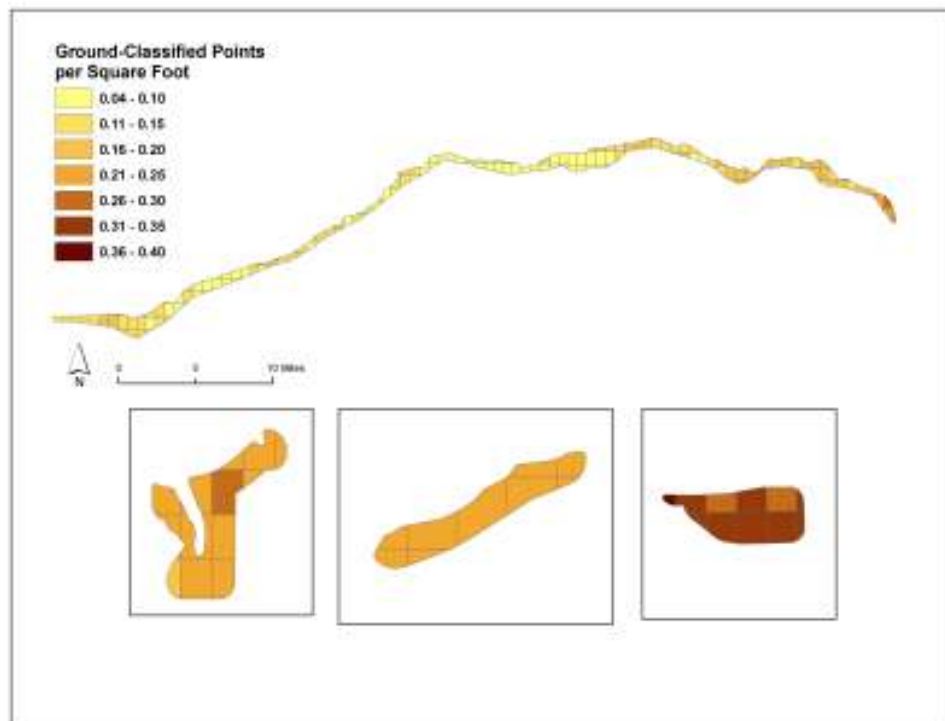


Figure 6. Density distribution map for ground return points by USGS 0.75 minute quads.



5.3 Relative Accuracy Calibration Results

Relative accuracies for the OPRD survey area measure the full survey calibration including areas outside the delivered boundary. Statistics reflect processing directed towards the calibration of the larger USACE dataset of which the OPRD survey is a portion.

Relative accuracy statistics for OPRD study areas:

- Project Average = 0.15 ft (0.05 m)
- Median Relative Accuracy = 0.14 ft (0.04 m)
- 1 σ Relative Accuracy = 0.17 ft (0.05 m)
- 2 σ Relative Accuracy = 0.27 ft (0.08 m)

Figure 7. *Distribution of relative accuracies per flight line, non slope-adjusted.*

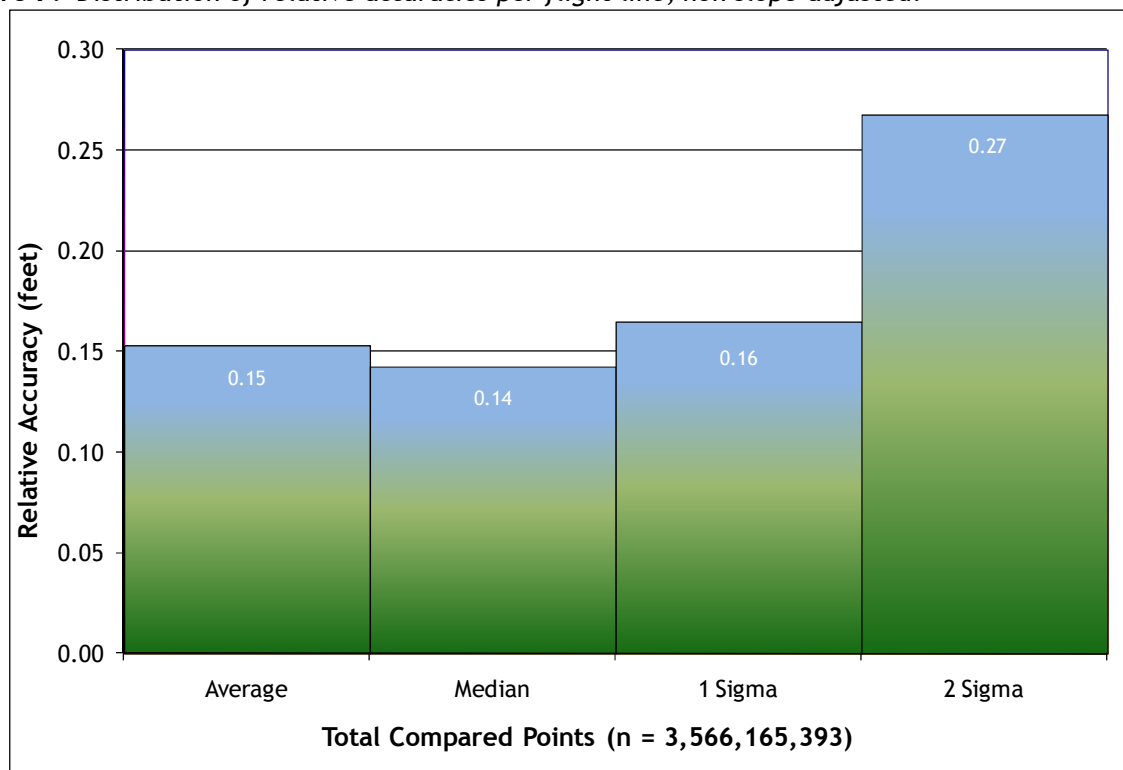
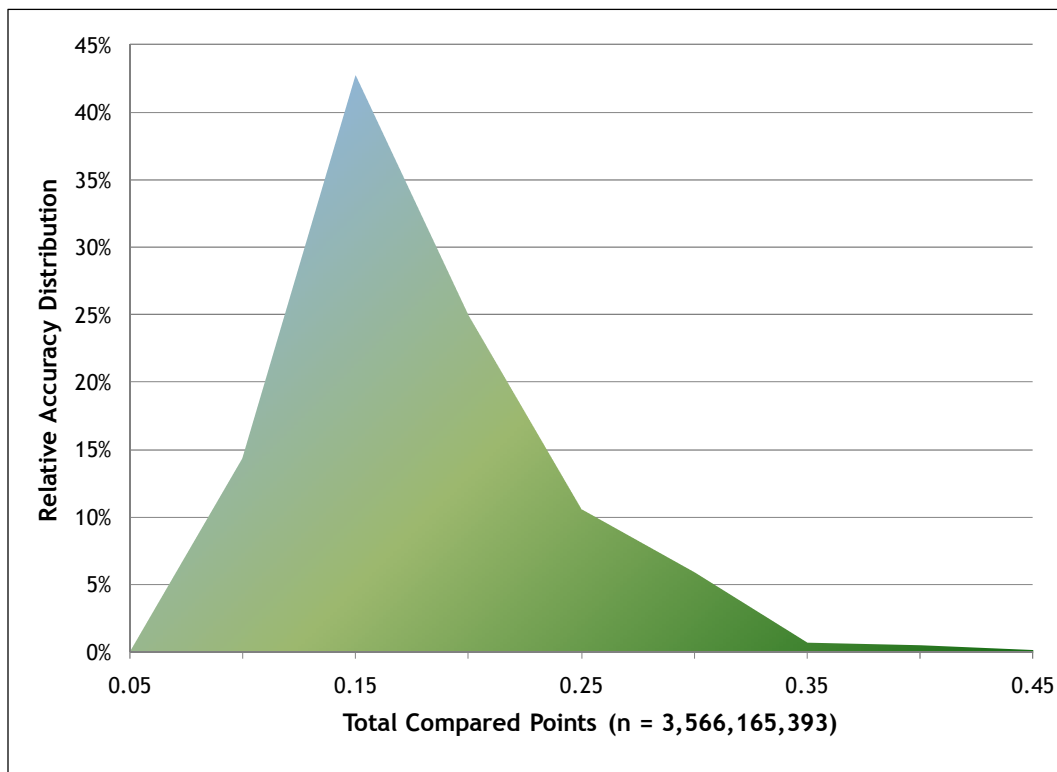


Figure 8. *Percentage distribution of relative accuracies, non slope-adjusted.*



5.4 Absolute Accuracy

Absolute accuracies for the OPRD survey areas:

Table 4. Absolute Accuracy - Deviation between laser points and RTK survey points

RTK Survey Sample Size (n): 4,293	
Root Mean Square Error (RMSE) = 0.14 ft (0.04 m)	Minimum Δz = -0.50 ft (-0.15 m)
1 sigma (σ): 0.15 ft (0.05 m)	Maximum Δz = 0.43 ft (0.13 m)
2 sigma (σ): 0.28 ft (0.09 m)	Average Δz = -0.03 ft (-0.01 m)

Figure 9. OPRD Study Area histogram statistics

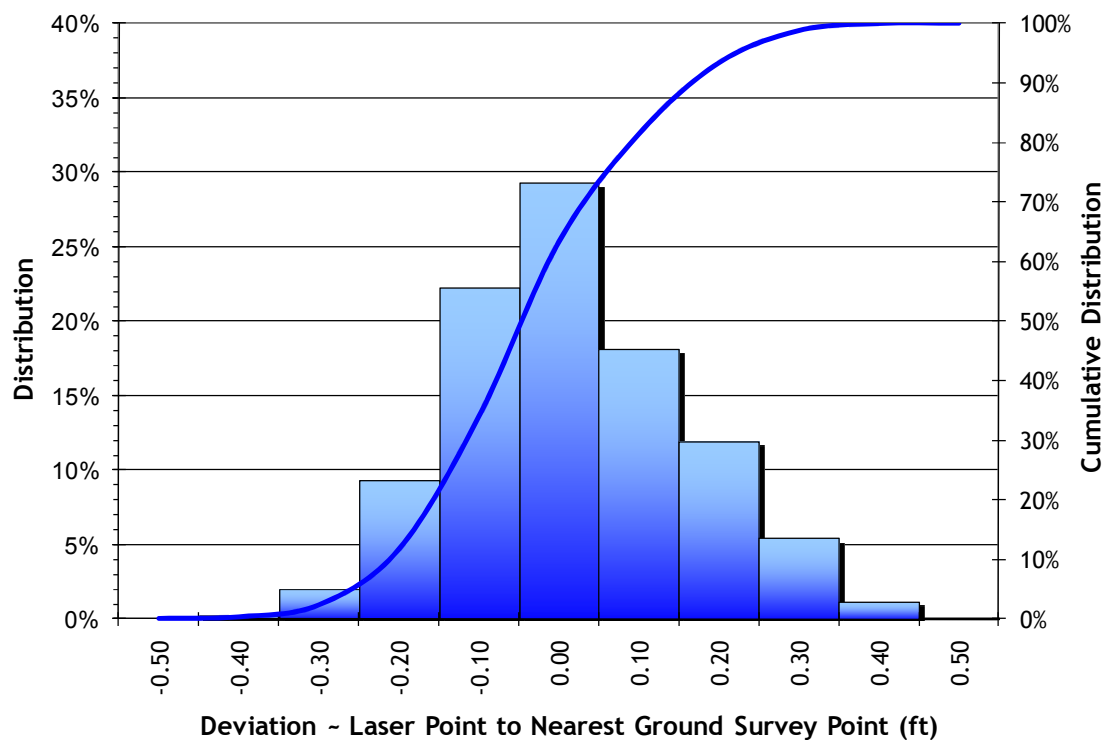
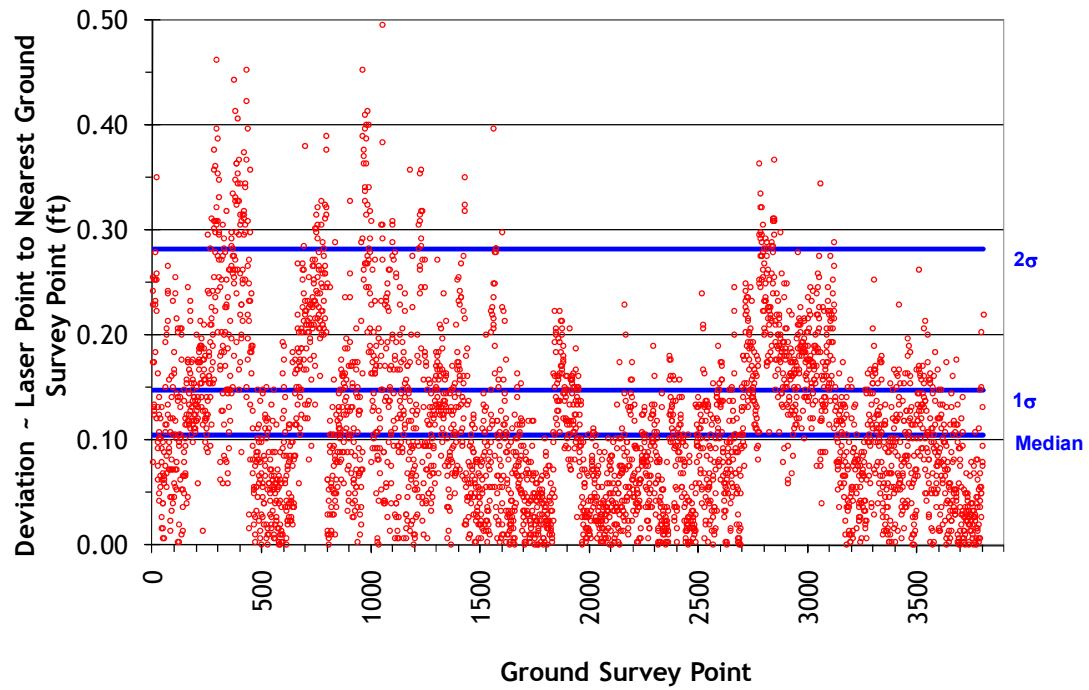


Figure 10. OPRD Study Area point absolute deviation statistics



7. Projection/Datum and Units

Projection:		Oregon Statewide Lambert (OGIC)
Datum	Vertical:	NAVD88(Geoid09)
	Horizontal:	NAD83(CORS96)*
Units:		International feet

*Native .las data were collected in NAD83(CORS96). The deliverable data products produced in the ESRI software environment are defined as NAD83(HARN), which is the closest approximation to the CORS96 version of NAD83 offered by ESRI as a standard horizontal coordinate system.

8. Deliverables

Point Data:	<ul style="list-style-type: none">• All Returns (LAS 1.2 format)• Ground Classified Points (LAS 1.2 format)
Vector Data:	<ul style="list-style-type: none">• Tile Index of LiDAR All Returns points (USGS 0.75 minute quads, with high density tiles subset into quarters, shapefile)• Tile Index of LiDAR Ground Classified points and Intensity Images (USGS 0.75 minute quads, shapefile)• Tile Index of DEM rasters (USGS 3.75 minute quads, shapefile)• 1-hz SBET files (shapefile)• RTK Ground Survey point positions (shapefile)• Static GPS Base Station positions (shapefile)
Raster Data:	<ul style="list-style-type: none">• Elevation models (3 ft resolution)<ul style="list-style-type: none">• Bare Earth Model (ESRI GRID format)• Highest Hit Model (ESRI GRID format)• Intensity images (GeoTIFF format, 1.5 ft resolution)
Data Report:	Full report containing introduction, methodology, and accuracy

9. Selected Images



Figure 11. The city of Mosier, Oregon, and the mouth of Rock Creek. Image created from RGB values extracted from a NAIP orthophoto onto a three dimensional LiDAR point cloud.



Figure 12. View downstream over the mouth of the Deschutes River near Biggs Junction, Oregon. Image created from RGB values extracted from a NAIP Orthophoto onto a three dimensional LiDAR point cloud.

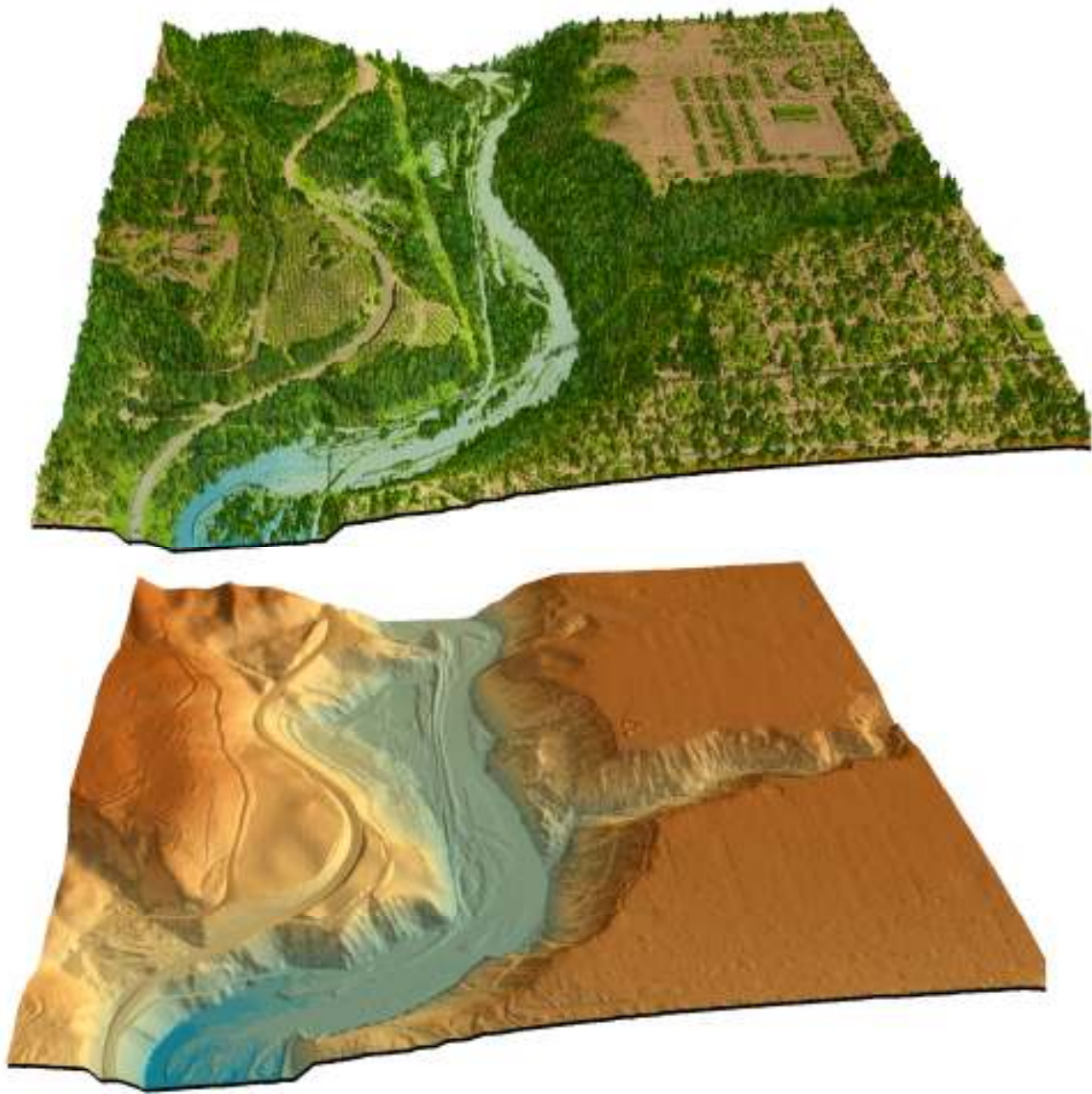


Figure 13. View upstream on Hood River, just south of the town of Hood River, Oregon. Top image was created from a model of three dimensional LiDAR point cloud while lower image was created from ground-classified LiDAR point cloud.

10. Glossary

1-sigma (σ) Absolute Deviation: Value for which the data are within one standard deviation (approximately 68th percentile) of a normally distributed data set.

2-sigma (σ) Absolute Deviation: Value for which the data are within two standard deviations (approximately 95th percentile) of a normally distributed data set.

Root Mean Square Error (RMSE): A statistic used to approximate the difference between real-world points and the LiDAR points. It is calculated by squaring all the values, then taking the average of the squares and taking the square root of the average.

Pulse Rate (PR): The rate at which laser pulses are emitted from the sensor; typically measured as thousands of pulses per second (kHz).

Pulse Returns: For every laser pulse emitted, the Leica ALS 50 Phase II system can record *up to four* wave forms reflected back to the sensor. Portions of the wave form that return earliest are the highest element in multi-tiered surfaces such as vegetation. Portions of the wave form that return last are the lowest element in multi-tiered surfaces.

Accuracy: The statistical comparison between known (surveyed) points and laser points. Typically measured as the standard deviation (sigma, σ) and root mean square error (RMSE).

Intensity Values: The peak power ratio of the laser return to the emitted laser. It is a function of surface reflectivity.

Data Density: A common measure of LiDAR resolution, measured as points per square meter.

Spot Spacing: Also a measure of LiDAR resolution, measured as the average distance between laser points.

Nadir: A single point or locus of points on the surface of the earth directly below a sensor as it progresses along its flight line.

Scan Angle: The angle from nadir to the edge of the scan, measured in degrees. Laser point accuracy typically decreases as scan angles increase.

Overlap: The area shared between flight lines, typically measured in percents; 100% overlap is essential to ensure complete coverage and reduce laser shadows.

DTM / DEM: These often-interchanged terms refer to models made from laser points. The digital elevation model (DEM) refers to all surfaces, including bare ground and vegetation, while the digital terrain model (DTM) refers only to those points classified as ground.

Real-Time Kinematic (RTK) Survey: GPS surveying is conducted with a GPS base station deployed over a known monument with a radio connection to a GPS rover. Both the base station and rover receive differential GPS data and the baseline correction is solved between the two. This type of ground survey is accurate to 1.5 cm or less.

11. Citations

Soininen, A. 2004. TerraScan User's Guide. TerraSolid.

Appendix A

LiDAR accuracy error sources and solutions:

Type of Error	Source	Post Processing Solution
GPS (Static/Kinematic)	Long Base Lines	None
	Poor Satellite Constellation	None
	Poor Antenna Visibility	Reduce Visibility Mask
Relative Accuracy	Poor System Calibration	Recalibrate IMU and sensor offsets/settings
	Inaccurate System	None
Laser Noise	Poor Laser Timing	None
	Poor Laser Reception	None
	Poor Laser Power	None
	Irregular Laser Shape	None

Operational measures taken to improve relative accuracy:

1. Low Flight Altitude: Terrain following is employed to maintain a constant above ground level (AGL). Laser horizontal errors are a function of flight altitude above ground (i.e., $\sim 1/3000^{\text{th}}$ AGL flight altitude).
2. Focus Laser Power at narrow beam footprint: A laser return must be received by the system above a power threshold to accurately record a measurement. The strength of the laser return is a function of laser emission power, laser footprint, flight altitude and the reflectivity of the target. While surface reflectivity cannot be controlled, laser power can be increased and low flight altitudes can be maintained.
3. Reduced Scan Angle: Edge-of-scan data can become inaccurate. The scan angle was reduced to a maximum of $\pm 15^\circ$ from nadir, creating a narrow swath width and greatly reducing laser shadows from trees and buildings.
4. Quality GPS: Flights took place during optimal GPS conditions (e.g., 6 or more satellites and PDOP [Position Dilution of Precision] less than 3.0). Before each flight, the PDOP was determined for the survey day. During all flight times, a dual frequency DGPS base station recording at 1-second epochs was utilized and a maximum baseline length between the aircraft and the control points was less than 19 km (11.5 miles) at all times.
5. Ground Survey: Ground survey point accuracy (i.e. <1.5 cm RMSE) occurs during optimal PDOP ranges and targets a minimal baseline distance of 4 miles between GPS rover and base. Robust statistics are, in part, a function of sample size (n) and distribution. Ground survey RTK points are distributed to the extent possible throughout multiple flight lines and across the survey area.
6. 50% Side-Lap (100% Overlap): Overlapping areas are optimized for relative accuracy testing. Laser shadowing is minimized to help increase target acquisition from multiple scan angles. Ideally, with a 50% side-lap, the most nadir portion of one flight line coincides with the edge (least nadir) portion of overlapping flight lines. A minimum of 50% side-lap with terrain-followed acquisition prevents data gaps.
7. Opposing Flight Lines: All overlapping flight lines are opposing. Pitch, roll and heading errors are amplified by a factor of two relative to the adjacent flight line(s), making misalignments easier to detect and resolve.